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Our ref: 0503-3713957 /Amy Nelson

TITLE

IMAGE SENSOR WITH IMPROVED UNIFORMITY OF EFFECTIVE INCIDENT

LIGHT

BACKGROUND OF THE INVENTION

5 Field of the Invention

This invention relates generally to image sensors. In particular, it relates to a design for image sensor microlenses to improve uniformity of effective incident light at different regions.

10 Description of the Related Art

Solid state image sensors are necessary components in many optoelectronic devices, including digital cameras, cellular phones, and toys. Conventional image sensors include both charge coupled device (CCD) image sensors and 15 complementary metal oxide semiconductor (CMOS) image sensors. The basic technology used to form the CMOS image sensor is common to both types sensors.

The CMOS image sensor comprises a photo detector for detecting light and a logic circuit for converting the 20 detected light into an electric signal representing data regarding the detected light. The fill factor, sometimes referred to as the aperture efficiency, is the ratio of the size of the light-sensitive area to the size of the total pixel size. Although efforts have been made to increase the 25 fill factor of the image sensor and thereby increase the sensor sensitivity, further increases in the fill factor are limited because the associated logic circuitry cannot be

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completely removed. Accordingly, in order to increase the sensitivity of the light, a microlens formation technology has been used to converge and focus the incident light onto the photo detector by changing the path of the light that reaches the lens of the photo detector. In order for the image sensor to detect and provide a color image, it typically must include both a photo detector for receiving the light and generating and accumulating charge carriers and a color filter array (CFA), i.e., a plurality of color filter units sequentially arranged above the photo detector. The CFA typically uses one of two alternative three-color primary configurations, either red R, green G and blue B (RGB) or yellow Y, magenta M and cyan C (CMY). A plurality of microlenses are positioned above the color filter array to increase the photo-sensitivity of the image sensor.

In the following, a conventional CCD image device will be explained.

FIG. 1 is a cross-sectional view showing a conventional solid-state image device. In FIG. 1, reference numeral 13 represents a semiconductor substrate provided with a solid-state image sensor; 12 represents a p-well formed in the semiconductor substrate 13; 11 represents a photodiode; 10 represents a charge transfer part; 9 represents a silicon oxide or nitride film; 8 represents a polysilicon electrode; 14 represents a photo-shielding metal layer; 25 represents a surface protective coating of semiconductor elements; 19 represents a planarization layer for setting elements thereon; 24 represents a color filter array; 23 represents an intermediate transparent film; and 21 represents 30 microlenses. Furthermore, another conventional example

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comprises one additional layer of metal film formed via a silicon oxide film on the photo-shielding metal layer 14 for strengthening the photo-shielding and forming a semiconductor element with the surface protective coating 5 25. A microlens 21 is adjusted and positioned corresponding to each photodiode, and light converged by the lens is directed to the photodiode 11 to enhance sensitivity. Among electrons and holes arising from photoenergy in the photodiode 11, the electrons are forwarded to the charge 10 transfer part 10 by voltage applied to the polysilicon electrode 8. The transferred electrons are then forwarded to an output part by potential energy created in the charge transfer part 10 through the voltage applied to the polysilicone electrode 8.

15 Examples of various forms of the solid state sensor structures are to be found in the prior art. Okamoto (U.S. Patent No. 6,545,304 B2) discloses a photoelectric converter element group on one section of a semiconductor substrate and a charge transfer path to transfer accumulated signal 20 charge to a contiguous readout gate region having a readout gate electrode associated therewith. Umetsu et al. (U.S. Patent No. 6,528,831 B2) discloses a solid state image pickup device in which a matrix array of photoelectric sensors are formed adjacent to charge transfer channels and 25 wherein a read-cum-transfer electrode is formed on an insulating layer and surrounds each photoelectric element. These devices are cited here as examples of a CCD type sensor device.

In general, the image sensor is built in a chip, and 30 the microlenses corresponding to the photo detectors are

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arranged in a matrix. The solid state image sensor is placed where light is converged by an optical lens and an image is formed. However, the image captured on the edge region of the matrix is darker than that in the center
5 region.

As shown in FIG. 2, when the incident light R_0 transmits into the microlens 21 and through the stacked transmission layer comprising the color filter layer 27 and an IC transparent stacked layer 29 in the left pixel P_0 with
10 a chief angle $\theta = 0^\circ$, the incident light R_0 is focused on the sensing area 11 of the photo detector. This ideal situation of a chief angle $\theta = 0^\circ$ occurs at the center region of the sensor chip 10. But if the incident light R_1 transmits into the microlens 21 with a chief angle θ other
15 than 0° , the incident light reaching the photo detector may shift outside the sensing area 11. The phenomenon is especially problematic for microlenses 21 disposed near the edge region of the sensor chip 10. The pixel P_1 shown in the middle of FIG. 2 is between the center region and the
20 edge region of the sensor chip 10, and the right pixel P_2 is arranged in the edge region. In pixels P_1 and P_2 , the ideal incident light I is uniformly collimated light shown by dashed lines, while the real incident light R_1 and R_2 is shown by solid lines transmitted into the microlens 21 with
25 chief angles θ_1 and θ_2 , and $\theta_1 < \theta_2$. Therefore, the sensing area 11 corresponding to the incident light R_1 and R_2 transmitted with a chief angle $\theta > 0^\circ$ obtains less photoenergy than the sensing area 11 corresponding to the incident light R_0 transmitted with a chief angle 0° .

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The traditional method to resolve the issue of shift of the focus center is shifting the microlens 21 to correct the focus center of the incident light within the sensing area 11. As shown in FIG. 3, the microlens 21' before shifting 5 is aimed at the sensing area 11_R of the right pixel P_R and the incident light R_b passing through the color filter layer 27_R falls outside the sensing area 11_R. After shifting, the shifted microlens 21 can focus the incident light R_f on the right pixel P_R. However, microlenses 21 near the boundary 10 of the chip may be shifted so much that the incident light R_f passes through the adjacent color filter layer 27_L and cross-talk phenomenon CT occurs in the adjacent pixels P_L and P_R.

SUMMARY OF THE INVENTION

15 Accordingly, it is the object of this invention to provide an image sensor that obtains more uniform photoenergy in different regions of the chip, especially the center region and the edge region.

It is another object of this invention to provide an
image sensor that avoids the cross-talk problem.

To achieve the above objects, an image sensor is designed following the condition that the size of each microlens is a function of the radial distance (hereafter referred as distance) between the microlens to a chip center. Therefore, the sizes of the microlenses are not the same so as to resolve the issue of non-uniform incident light in different regions.

In another embodiment of the present invention, an image sensor is designed following the condition that the

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distance between a center of the microlens and a center of a corresponding sensing area is a function of the distance between the corresponding sensing area, such as a photodiode, to a chip center, and each microlens is disposed overlying a corresponding color filter unit without overlying adjacent color filters. Therefore, the issue of non-uniform incident light is improved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view showing an image pick-up part of a conventional solid-state image device.

FIG. 2 shows a cross-sectional view of three pixels in which real incident light with different chief angles reaches the photo detectors in the center region, middle region and edge region of the sensor chip.

15 FIG. 3 is a cross-sectional view showing a microlens shifted toward the chip center resulting in cross-talk phenomenon.

FIG. 4 shows the sensor chip divided into three regions, each equipped with one size of microlenses based on the distance of the region and the chip center in accordance with an embodiment of the present invention.

FIG. 5 shows an ideal arrangement and the modified arrangement of the microlenses, the color filter units and the photosensitive elements in the front three groups, 1, 2 and 3.

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DETAILED DESCRIPTION OF THE INVENTION

First embodiment

The incident light transmitted into the microlenses and reaching the sensing areas of an image sensor may not uniformly collimated light, especially for the regions away from the chip center. Therefore the image displayed on the edge region is darker than the center region.

The present invention provides a method improving the uniformity of effective incident light and avoiding cross-talk between adjacent pixels in a chip equipped with an image sensor so as to balance the brightness in different regions. The microlens layer consists of a plurality of microlenses corresponding to a plurality of sensing areas, respectively. The size of microlens is a function of the distance between microlens to the chip center. Specifically, the size of microlens increases as the distance between the microlens to the chip center increases.

Progressively increasing the size of the microlenses from the chip center to a chip edge balances the brightness in different regions of the chip. In practice, changing the size of each microlens is not easy. Therefore, the chip maybe divided to several regions, each region having the same size of microlenses, wherein the sizes in different region are based on the distance between the region and the chip center. For example, the chip 100, as shown in FIG. 4, has a chip center C, and is divided into three regions. The region A₁ is a round area from the chip center C to the radius r₁, the region A₂ is an annular area encircling the region A₁ from the radius r₁ to the radius r₂, and the region

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A_3 is a ringlike region encircling the region A_2 from the radius r_2 to the edge of the chip 100. The microlenses disposed in the region A_1 , A_2 and A_3 have a constant size S_1 , S_2 and S_3 , respectively, wherein $S_1 < S_2 < S_3$. The 5 photoenergy received by the sensing areas of the center region A_1 and the edge region A_3 are almost uniform resulting, in the balance of the brightness in different regions.

In order to balance the difference of the brightness, 10 the center region may be made a little darker, or the edge region a little brighter. In the former, the microlenses disposed in the chip edge region are kept at an original size, which means the typical design without considering the difference of the chief angles, while the size of the 15 microlenses disposed in the center region is reduced 5-50 %, wherein about 20% is preferred, compared to the size of the microlenses disposed in the edge region.

Second embodiment

The present invention provides a method to improve non-uniformly effective incident light and to avoid cross-talk between adjacent pixels in a sensor chip. The microlens layer consists of a plurality of microlenses corresponding to each sensing area. The position of the microlens is a function of distance from the microlens to the chip center. 25 Specifically, the microlens is shifted toward the chip center as the distance between the microlens and the chip center increases. If the microlens is shifted, the corresponding color filter is also shifted to make sure the incident light does not pass through the adjacent color 30 filter.

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A sensor chip with 1284×1028 pixels is given as an example. Each pixel has a width of $4 \mu\text{m}$. The chief angle in the edge region furthest away from the chip center is 15° and the furthest microlens needs to be shifted $2.1 \mu\text{m}$. The 5 pixels are divided into 31 groups. The relationship between the chief angle and shifting amounts of the microlens and the color filter unit is shown in TABLE 1.

10 TABLE 1 relationship between chief angle
and group shift

Chief angle	Shifting amount of focus center of incident light (μm)	Shifting amount of microlens and color filter unit (μm)	Group
0°	0	0	1
		0.07	2
1°	0.14	0.14	3
		0.21	4
2°	0.28	0.28	5
		0.35	6
3°	0.42	0.42	7
		0.49	8
4°	0.56	0.56	9
		0.63	10
5°	0.70	0.70	11
		0.77	12
6°	0.84	0.84	13
		0.91	14
7°	0.98	0.98	15
		1.05	16
8°	1.12	1.12	17
		1.19	18
9°	1.26	1.26	19
		1.33	20
10°	1.40	1.40	21
		1.47	22
11°	1.54	1.54	23
		1.61	24

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12°	1.68	1.68	25
		1.75	26
13°	1.82	1.82	27
		1.89	28
14°	1.96	1.96	29
		2.03	30
15°	2.10	2.10	31

FIG. 5 shows an typical arrangement (lower portion of the figure, B) and the modified arrangement of the present invention (upper portion of the figure, A) of the 5 microlenses 21, the color filter units 24 and the sensing areas 11 in the front three groups, 1, 2 and 3. The microlenses 21 are shown as simple rectangular shapes. 24 represents a plurality of color filter units which constitute a color filter array of a color filter layer. 29 10 represents an IC staked layer.

As shown in FIG. 5, the microlenses 21 and the color filter units 24 arranged in group 1 of the modified arrangement of the present invention are kept in the same position as those in the typical arrangement B.

15 In group 2, the microlenses 21 and the color filter units 24 are shifted toward the chip center by a distance of 0.07 μm . Therefore, the distance between the center of each microlens 21, notated as e, and the center of the corresponding sensing area 11, notated as f, is 0.07 μm . 20 Each microlens 21 should be disposed overlying the corresponding color filter unit 24 without overlying adjacent color filter units to avoid the cross-talk issue. Therefore, if the microlens 21 is shifted, so is the corresponding color filter unit 24. The microlenses 21 in 25 group 2 can be shifted by decreasing the gap between two

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adjacent microlenses 21 belonging to groups 1 and 2, while the other microlenses 21 in group 2 not adjacent to microlenses in group 1 can be shifted without decreasing the gaps there between. The color filter units 24 in group 2 5 can be shifted by reducing the size of the color filter unit 24 in group 2 adjacent to a color filter unit 24 belonging to group 1, while the other color filter units 24 in group 2 can be shifted without reducing their sizes.

In group 3, the microlenses 21 can be shifted by 10 decreasing the gap between two adjacent microlenses 21 belonging to groups 2 and 3, while the other microlenses 21 in group 3 not adjacent to microlenses in group 2 can be shifted without decreasing the gaps there between. The color filter units 24 in group 3 can be shifted by reducing 15 the size of the color filter unit 24 belonging to group 3 adjacent to the color filter unit 24 belonging to group 2, while the other color filter units 24 in group 3 can be shifted without reducing their sizes.

As is understood by a person skilled in the art, the 20 preferred embodiments of the present invention are illustrative of the present invention rather than limiting of the present invention. Revisions and modifications may be made to methods, materials, structures and dimensions employed in fabricating a packaged image sensor having 25 improved sensitivity, while still providing such a packaged image sensor having improved sensitivity as described herein, in accord with the spirit and scope of the present invention as defined by the appended claims.